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An analytic procedure is presented for testing the homogeneity of unstandardized regression weight vectors in the condition that the regression weight vectors are correlated. The basic design involves repeated measurements on a dependent variable and a set of independent variables in each of S time periods or situations. Use of the test is illustrated in a study of cross-situational consistency versus cross-situational specificity of the correlates of perceived leader behavior.

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A Multivariate Test of Homogeneity of Regression Weights
for Correlated Data

A test was proposed recently to evaluate homogeneity of unstandardized regression weights (b-weights) for regression equations constructed in two or more time periods for the same subjects (James, Joe, & Irons, in press). The experimental design involved relationships between two or more independent variables (e.g., selection tests) measured at a base time period (T_0), and repeated measurements taken later on the same dependent variable (e.g., a job performance criterion) at times T_1 through T_S. The test, referred to as a test of sequential moderation, assessed whether vectors of b-weights, constructed for each time period T_s ($s=1,\ldots,S$), differed as a function of time of measurement. Given the same subjects, the same data on independent variables, and, most likely, significant correlations among repeated measurements on the dependent variable, the test was designed to take into account covariation among the b-weight vectors.

The test for sequential moderation may be viewed as a specific form of a more general test of homogeneity of b-weight vectors for correlated data. The general form of the test is based on relaxing the assumption that independent variables are measured only once. For example, one might obtain repeated measurements on the same J independent variables (X_{js}, $j=1,\ldots,J$) and the same dependent variable (Y_s) in each of S time periods. Comparison of the S b-weight vectors furnishes a test of homogeneity of regressions, or, if the equations are regarded as structural equations, a test of

"stationarity" for a nonlagged time series design. Or, one could obtain measurements on a set of $\underline{X_{js}}$ at time $\underline{T_1}$ ($\underline{s}$=1) and a $\underline{Y_s}$ at time $\underline{T_2}$ ($\underline{s}$=2), and compare the $\underline{Y_2}$ on $\underline{X_{j1}}$ $\underline{b}$-weight vector with a $\underline{b}$-weight vector provided by a $\underline{Y_4}$ on $\underline{X_{j3}}$ regression. This design has the form of a lagged time series, where $\underline{X_{j3}}$ and $\underline{Y_4}$ reflect repeated measurements on the independent variables and the dependent variable at times $\underline{T_3}$ and $\underline{T_4}$, respectively.

The designs above are meant to be illustrative; the test is not limited to time series forms of analysis. Consider, as another example, the current refueling of the historical debate between consistency of behavior versus situational specificity (cf. Epstein, 1979, 1980; Kenrick & Stringfield, 1980; Kenrick & Braver, 1982; Magnusson & Endler, 1977; Ruston, Jackson & Paunonen, 1981). This debate could be assisted by asking whether the correlates of a behavior such as aggressiveness are homogeneous in different situations. In this case, $\underline{Y_s}$ assumes the role of the behavior for which consistency (specificity) is to be assessed, the $\underline{X_{js}}$ are presumed correlates of $\underline{Y_s}$, and variation in $\underline{s}$ reflects repeated measurements on $\underline{Y}$ and the $\underline{X_j}$ in different situations. Consistency (homogeneity) versus specificity (heterogeneity) of $\underline{b}$-weight vectors could add meaningful information regarding why the $\underline{Y_s}$ were or were not consistent over the $\underline{S}$ situations, as compared to the present reliance on tests of "relative consistency" (i.e., correlations between repeated measurements on $\underline{Y}$—cf. Epstein, 1979; Magnusson & Endler, 1977), which consider only information on $\underline{Y}$. An example of this form of application of the proposed test is presented later in this article.

Test of Homogeneity of Correlated Regression Weights

The derivations below employ many of the same basic assumptions used by James et al. (in press) to derive the test for sequential moderation, although the equations presented here are more complex because repeated measurements are now taken on the X_{js}. The null hypothesis (H_o) is $\Gamma_1 = \Gamma_2 = \ldots = \Gamma_s = \ldots \Gamma_S$, where Γ_s refers to the population b-weight vector associated with the regression of Y_s on the X_{js}. The same scales of measurement are employed for each variable at each time s, and the variables are presumed to be in deviation form. The development of the test was again predicated on extending a univariate t-test for correlated b-weights (Yates, 1939) to the multivariate case by (a) replacing scalars in the Yates equation (i.e., b_{11} and b_{12}) with vectors of b-weights (i.e., B_s, $J \geq 2$ is assumed); (b) using the logic of the Hotelling T^2 for correlated means and repeated measures ANOVA to develop a test for two b-weight vectors (i.e., $S=2$); and (c) extending the test for two b-weight vectors to more than two vectors (i.e., $S > 2$) by the use of common regression hyperplanes. The test for $S > 2$ may also be employed for $S = 2$ vectors, and thus only one set of derivations is required.

It is assumed throughout the derivations that differences between two b-weight vectors and the difference between each b-weight vector and a common regression vector have an underlying multivariate normal distribution (James et al., in press; Yates, 1939). In addition, Yates (1939) assumed that the independent variables were error-free and fixed. In the typical application, the design will involve independent variables that are both

random variables and not perfectly reliable. However, if (a) a conditional normal model is assumed (Cramer & Appelbaum, 1978), and if (b) the independent variables are required to have high reliabilities, then (c) the assumptions underlying the use of the $\underline{T}^2$ statistic, and extension to $\underline{S} > 2$, should be reasonably satisfied.

Given the design and assumptions above, application of the Hotelling $\underline{T}^2$ statistic for correlated data to the problem of testing correlated b-weight vectors with $\underline{S} = 2$ furnishes a hypothesis matrix, designated Q_H, and an error matrix, designated Q_E. The matrices have the following forms:

$$Q_H = (B_1 - B_2)(B_1 - B_2)' \qquad (1)$$

$$Q_E = V_{B_1} + V_{B_2} - C_{B_1B_2} - C_{B_2B_1} \qquad (2)$$

B_1 is the b-weight vector associated with the Y_1 on X_{j1} regression, and B_2 is the b-weight vector for the Y_2 on X_{j2} regression. V_{B_1} and V_{B_2} represent variances (and covariances) of each b-weight vector, and $C_{B_1B_2}$ is a matrix representing the covariances between the b-weight vectors. $C_{B_2B_1}$ is the transpose of $C_{B_1B_2}$.

For $\underline{S}>2$, we shall employ the logic of tests of homogeneity of b-weight vectors for independent groups (cf. Timm, 1975; Williams, 1959). When applied to repeated measures on the same group, the procedure consists of comparing the b-weight vector unique to each particular time $\underline{s}$, or B_s, to a vector comprised by b-weights that are common to all occasions (a common regression hyperplane), designated B_c. The logic of the test is that if H_o is not rejected, then B_c can be used at each time $\underline{s}$ without

increasing significantly the pooled residual sum of squares over the $\underline{S}$ occasions, as compared to the residual sum of squares obtained from the unique $\underline{B}_s$ when pooled over $\underline{S}$ occasions. In short, the $\underline{\Gamma}_s$, estimated by the $\underline{B}_s$, are regarded as homogeneous or parallel. Alternatively, rejection of $\underline{H}_o$ suggests that the $\underline{\Gamma}_s$ are heterogeneous or nonparallel, which corresponds to the finding that the use of $\underline{B}_c$ in each of $\underline{S}$ occasions results in a significant increase in the pooled residual sum of squares, as compared to the use of the unique $\underline{B}_s$ in each occasion (intercepts are not addressed in this article).

The equation for the hypothesis sum of squares and cross-products (SSCP) matrix (Q_H), given $\underline{S} \geq 2$, is as follows (James et al., in press):

$$Q_H = \sum_{\underline{s}} (\underline{B}_s - \underline{B}_c)(\underline{B}_s - \underline{B}_c)' \tag{3}$$

where:

$$\underline{B}_s = VC_{xx_s}^{-1}\, \underline{C}_{x_s y_s} \tag{4}$$

$$\underline{B}_c = \left(\sum_{\underline{s}} VC_{xx_s}\right)^{-1} \left(\sum_{\underline{s}} \underline{C}_{x_s y_s}\right) \tag{5}$$

$VC_{xx_s}^{-1}$ is the inverse of the $\underline{J}$ x $\underline{J}$ predictor variance-covariance matrix at time $\underline{s}$, $\underline{C}_{x_s y_s}$ is the $\underline{J}$ x 1 vector of covariances between the criterion $\underline{Y}$ and the $\underline{J}$ predictors at time $\underline{s}$, Q_H in Eq. 3 has an order of $\underline{J}$ x $\underline{J}$, and $\underline{B}_s$ (Eq. 4) and $\underline{B}_c$ (Eq. 5) have orders of $\underline{J}$ x 1.

For $\underline{S} > 2$, the equation for the residual SSCP matrix Q_E from Eq. 2 takes the general form:

$$Q_E = \sum_s V_{B_s} - \sum_{s<p} C_{B_s B_p} - \sum_{s<p} C_{B_p B_s} \quad (\text{for } s < p) \tag{6}$$

Two of the three main terms on the right side of Eq. 6 are expanded below; the derivations are based on Castellan (1973), Finn (1974), and James et al. (in press). The term $s < p$ implies $p = (s+1,\ldots,S)$, and applies only to the second and third terms on the right side of Eq. 6.

The expansion of the first term in Eq. 6 is as follows (cf. Finn, 1974):

$$\sum_s V_{B_s} = \sum_s [(1 - R_{Y_s}^{2}) V_{Y_s} SS_{xx_s}^{-1}] \tag{7}$$

where:

$R_{Y_s}^{2}$ = squared multiple correlation for the regression of Y_s on the X_{js} at time s;

V_{Y_s} = variance of Y at time s;

$SS_{xx_s}^{-1}$ = inverse of the $J \times J$ predictor SSCP matrix at time s.

The expansion of the covariances among the b-weight vectors in the second term in Eq. 6 is:

$$\begin{aligned} C_{B_s B_p} &= E\left[(B_s - \Gamma_s)(B_p - \Gamma_p)'\right] \\ &= C_{e_s e_p} SS_{xx_s}^{-1} S_{x_s x_p} SS_{xx_p}^{-1} \\ &= (C_{Y_s Y_p} - B_s' C_{Y_p x_s} - B_p' C_{Y_s x_p} + B_s' C_{x_s x_p} B_p) SS_{xx_s}^{-1} S_{x_s x_p} SS_{xx_p}^{-1} \end{aligned} \tag{8}$$

where, for terms not defined previously:

$\underline{E}$ = expectation operator;

$\underline{C_{e_s e_p}}$ = covariance among errors from $\underline{B_s}$ and $\underline{B_p}$ regression equations [expansion of this term was based on Castellan (1973)];

$\underline{C_{y_s y_p}}$ = covariance between $\underline{Y}$ measured at times $\underline{s}$ and $\underline{p}$;

$\underline{B_p}$ = $\underline{J}$ x 1 $\underline{b}$-weight vector unique to time $\underline{p}$; $\underline{p} > \underline{s}$;

$\underline{C_{y_p x_s}}$ = $\underline{J}$ x 1 covariance vector for $\underline{Y}$ measured at time $\underline{p}$ and the X_j measured at time $\underline{s}$;

$\underline{C_{y_s x_p}}$ = $\underline{J}$ x 1 covariance vector for $\underline{Y}$ measured at time $\underline{s}$ and the $\underline{X_j}$ measured at time $\underline{p}$;

$C_{x_s x_p}$ = square $\underline{J}$ x $\underline{J}$ matrix of the covariances among the $\underline{X_j}$ measured at times $\underline{s}$ and $\underline{p}$, respectively;

$S_{x_s x_p}$ = square $\underline{J}$ x $\underline{J}$ matrix of sums of cross-products among the $\underline{X_j}$ measured at times $\underline{s}$ and $\underline{p}$, respectively;

$SS_{xx_p}^{-1}$ = inverse of the $\underline{J}$ x $\underline{J}$ SSCP matrix for the $\underline{X_j}$ measured at time $\underline{p}$.

The third term, $\sum_{s<p} C_{B_p B_s}$, is based on the transpose of $C_{B_s B_p}$ and is not expanded here. C_E in Eq. 6 is of order $\underline{J}$ x $\underline{J}$.

A multivariate significance test is [other test criteria may be employed

(cf. Timm, 1979)]:

$$\underline{\Lambda} = \frac{|\underset{\sim}{Q}_E|}{|\underset{\sim}{Q}_H + \underset{\sim}{Q}_E|} \tag{9}$$

which follows the $\underline{U}$ distribution with [$\underline{S}$, $\underline{J}$ ($\underline{S}$-1), ($\underline{n}$-1)($\underline{S}$-1)-$\underline{S}$ $\underline{J}$] degrees of freedom, where $\underline{n}$ is the number of subjects. A significant $\underline{\Lambda}$ indicates rejection of the null hypothesis that the b-weight vectors are homogeneous (parallel) for repeated measurements on $\underline{Y}$ and the $\underline{X_j}$ over $\underline{S}$ time periods.

It is noteworthy that a significant $\underline{\Lambda}$ could be a function of various statistical inadequacies and artifacts. These include (a) differential reliabilities of $\underline{Y}$ and/or the $\underline{X_j}$ at different points in time; (b) differential rates of stability in $\underline{Y}$ and/or the $\underline{X_j}$ over time; and (c) unstable regression coefficients resulting from high intercorrelatins among the $\underline{X_j}$ for each time $\underline{s}$. Careful consideration should be given to short-term reliabilities, long-term stabilities (cf. Heise, 1969), and relations among the $\underline{X_{js}}$ (cf. Gordon, 1968) before the test for homogeneity of correlated b-weight vectors is employed. In addition, the usual assumptions regarding the use of multiple regression at each time of measurement are applicable, in particular additivity and linearity (cf. Cohen & Cohen, 1975). The sample should be sufficiently large to furnish stable estimates of regression parameters and meaningful power for the test. However, the power furnished by

large samples suggests that differences among *b*-weight vectors should be of practical as well as statistical significance.

Empirical Illustration

An example of the use of Eq. 9 is based on a study of cross-situational consistency versus cross-situational specificity of the correlates of perceived leader behavior (James & White, Note 1). Navy leaders (n=377, Petty Officers through Commanders) completed a questionnaire in which they described subordinates in each of two conditions (S=2), namely a "Highest Performance Condition" (s=1) and a "Lowest Performance Condition" (s=2). The Highest Performance Condition (HP condition) was operationalized as follows. First, each leader selected his/her best overall performer and poorest overall performer (a form of extreme groups analysis). Second, each leader was given a seven category taxonomy of stress situations applicable to Navy personnel (e.g., time overload, task difficulty, underload), from which the leader selected the stress categories in which his/her best and poorest performers had their *highest* levels of performance, respectively. Third, for each performer, the leader described the overall performance of that subordinate in the stress category selected for him/her, the perceived attributions (causes) of that performance, and the leader behaviors used by the leader toward the subordinate.

A similar process was used to operationalize the Lowest Performance Condition (LP condition). The leader selected the stress categories in which the (same) best and poorest performers had their *lowest* levels of

performance, respectively. The items used in the HP condition to obtain measurements on each subordinate's performance, attributions of that performance, and leader behaviors used for each subordinate were again used in the LP condition.

It was hypothesized that leader behaviors, subordinate performance, and attributions of a subordinate's performance would be cross-situationally specific. Operationally, cross-situational specificity was indicated if (a) means on leader behaviors, performance, and attributions varied as a function of the HP versus LP conditions; (b) the bivariate correlations between repeated measures (HP and LP conditions) on the leadership, performance, and attribution variables were not high; and (c) the regressions of a leader behavior (Y_s) on the presumed correlates of leadership, namely subordinate performance and attributions of that performance (the X_{js}), varied as a function of performance condition. The first two criteria for cross-situational specificity indicate lack of "absolute consistency" and "relative consistency", respectively (cf. Magnusson & Endler, 1977; Epstein, 1979, 1980). The third criterion was viewed as a test of the relative consistency of the correlates of leader behaviors, and furnished information that should help to explain why a leader behavior was cross-situationally specific or consistent (James & White, Note 1).

Descriptive statistics and tests of absolute and relative consistency are summarized in Table 1. Correlations among variables are presented in Table 2. The results of an application of Eq. 9 to test for homogeneity of correlated regression weights are reported in Table 3.

Insert Tables 1, 2, and 3 about here

A leader behavior designated "control" was used for illustrative purposes. The control variable was a composite of four items designed to assess persuasive power and coercive power (e.g., Orally reprimand the subordinate--cf. Kipnis & Cosentino, 1969). A five-point, Likert-type scale was employed in the measurement of each item (1 = Not at all,...,5 = To a very great extent). With respect to correlates of control, subordinate performance was assessed by the item: Subordinate's overall performance in (stress) situation with highest (lowest) level of performance (1 = Very low,...,6 = Truly exceptional). An internal attribution variable was based on a composite of four items (subordinates' competence, attitude, effort, and leadership skills). Four external attribution items (variables 4 through 7, Table 1) were not homogeneous and therefore were treated separately. The scale for the internal and external attribution items was: -2 = Hurt performance strongly,..., 0 = Had no effect,..., +2 = Helped performance strongly (Meyer, 1980).

In regard to Table 1, multivariate (not shown) and univariate tests of means indicated a clear lack of absolute consistency for all of the variables. Relative consistency (similarity of rank order) was also rejected Correlations between repeated measurements on the same variable in the HP and LP conditions varied between .33 and .67, all of which were less than an arbitrarily set criterion of .70 (i.e., a correlation $\geq$ .70 was specified as

indicating cross-situational consistency). Thus, the data provided reasonable support for cross-situational specificity. It might also be noted that (a) the correlations were likely biased in a positive (high) direction due to the use of an extreme groups design, and (b) significant differences between means (a form of validity) for single item variables suggested that these variables were reliable.

The null hypothesis for the homogeneity test reported in Table 3 was $\Gamma_1 = \Gamma_2$, where Γ_1 and Γ_2 refer to population Y_s on X_{js} regression weight vectors for the HP and LP conditions, respectively. The sample estimates of Γ_1 and Γ_2 (B_1 and B_2), as well as estimates of common regression weights (B_c), are shown in Section A of Table 3. The squared multiple correlations (R^2s) for the HP and LP conditions were similar and of moderate magnitude. However, comparison of B_1 with B_2 indicated differences, especially in regard to subordinate performance, task difficulty, resources, and time. On the other hand, suppressor effects were in evidence for three of the four external attribution items (task difficulty in the B_2 vector and resources and time in the B_1 vector). This, coupled with the fact that the regression weights for these variables were nonsignificant in both B_1 and B_2, suggested that a test of homogeneity of regression weights could result in rejection of the null hypothesis based on nonsignificant predictors with weights of questionable generalizability (i.e., suppressor effects). Consequently, the decision was made to delete task difficulty, resources, and time from the regression analyses.

Reanalyses of the remaining data are shown in Section B of Table 3. The

R^2s remained moderate, and a difference in regression weights appeared likely for subordinate performance and, to a lesser extent, the leader's contribution (to a subordinate's performance) variable. Use of Eq. 9 to test for homogeneity of regression weights, reported in Section C of Table 3, supported this view. The Λ of .314 was significant ($p < .001$), which connoted that the regression of a leader's use of control on the independent variables was moderated by (a function of) performance condition. In particular, it appeared that self-perceptions of controlling behaviors were more contingent on perceived subordinate performance in the LP condition than in the HP condition. It is also possible that the leaders were less likely to assume responsibility for contributions to a subordinate's performance in the LP condition, as compared to the HP condition. Thus, in concert with the data presented in Table 1, cross-situational specificity in leadership was again indicated.

Discussion

A procedure has been presented for testing homogeneity of correlated regression weights. The test is expected to have multiple uses in areas such as time series analysis and, as illustrated, tests of cross-situational specificity versus consistency. Additional efforts are required (a) to develop post hoc tests to assess the contributions of single independent variables to the overall difference in correlated regression weight vectors, and (b) to extend the test to include multiple criteria. Finally, it is important to reiterate that the test is likely to furnish biased results if assumptions for multiple regression are unsatisfied and/or if statistical

artifacts, such as differential rates of stability in independent/dependent variables, are present in the data.

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1. James, L. R., & White, J. F. _Cross-situational specificity in managers' perceptions of subordinate performance, attributions, and leader behaviors._ Office of Naval Research Technical Report GT-ONR-2(1982), School of Psychology, Georgia Institute of Technology, Atlanta, Georgia.

Footnotes

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Table 1

Descriptive Statistics and Tests of Absolute Consistency (Means) and Relative Consistency (Correlations)

	HPC			LPC				
Variable	α	$\bar{X}$	SD	α	$\bar{X}$	SD	t	r
Dependent Variable								
1. Control	.81	11.73	3.83	.82	12.78	3.75	-8.31*	.58*
Independent Variables								
2. Subordinate Performance	NA	4.03	1.31	NA	2.44	1.17	40.95*	.64*
3. Internal Attributions	.86	2.54	3.91	.89	-1.26	3.46	34.44*	.67*
4. Task Difficulty	NA	.39	.98	NA	-.24	.91	17.76*	.47*
5. Resources	NA	.29	1.06	NA	-.15	.97	12.06*	.51*
6. Time	NA	.21	1.07	NA	-.27	.92	11.36*	.33*
7. Leader's Contribution	NA	.87	.67	NA	.57	.77	10.05*	.35*

Notes. n = 756 subordinates in each condition, HPC = Highest Performance Condition, LPC = Lowest Performance Condition, α = Cronbach alpha, t = correlated t test of means for HPC versus LPC, NA = not applicable, r = correlation between HPC and LPC conditions.

*$p < .01$

Table 2

Correlations in Highest and Lowest Performance Conditions

Variables	1	2	3	4	5	6	7
1. Control	--	-.40	-.42	-.23	-.04	-.05	.12
2. Subordinate Performance	-.41	--	.78	.40	.15	.14	.22
3. Internal Attributions	-.40	.68	--	.47	.21	.24	.27
4. Task Difficulty	-.09	.29	.38	--	.32	.30	.16
5. Resources	-.02	.04	.18	.33	--	.45	.17
6. Time	-.14	.07	.12	.29	.39	--	.17
7. Leader's Contribution	.17	.13	.23	.17	.22	.14	--

Note. $n = 754$; $p < .05 = .07$; correlations below the diagonal are for the highest performance condition; correlations above the diagonal are for the lowest performance condition.

Table 3

Test of Homogeneity of Correlated Regression Weights for

Correlates of Leader's Use of Control

A. Unstandardized Regression Weights

Variable	B_1 (HPC)	B_2 (LPC)	B_c (Common)
Subordinate Performance	-.504*	-.838*	-.667
Internal Attributions	-.331*	-.322*	-.323
Task Difficulty	-.214	.278	.018
Resources	.094	-.065	.030
Time	.074	-.172	-.028
Leader's Contribution	1.400*	1.300*	1.345
R^2	.251	.267	

B. Unstandardized Regression Weights

Variable	B_1 (HPC)	B_2 (LPC)	B_c (Common)
Subordinate Performance	-.525*	-.810*	-.667
Internal Attributions	-.342*	-.309*	-.321
Leader's Contribution	1.423*	1.290*	1.348
R^2	.248	.262	

C. Test of Homogeneity

Source	Determinant Value	Λ	df
Q_E	$.272 \times 10^{-5}$	.314*	2, 3, 747
$Q_E + Q_H$	$.865 \times 10^{-5}$		

*p < .001

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